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Original Article

Effects of aging on sleep structure throughout adulthood: a population-based study

Walter Moraes *, Ronaldo Piovezan, Dalva Poyares, Lia Rita Bittencourt, Rogerio Santos-Silva, Sergio Tufik

Universidade Federal de São Paulo, São Paulo, Brazil

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Objective: Although many studies have shown the evolution of sleep parameters across the lifespan, not many have included a representative sample of the general population. The objective of this study was to describe age-related changes in sleep structure, sleep respiratory parameters and periodic limb movements of the adult population of São Paulo.
Methods: We selected a representative sample of the city of São Paulo, Brazil that included both genders and an age range of 20–80 years. Pregnant and lactating women, people with physical or mental impairments that prevent self-care and people who work every night were not included. This sample included 1024 individuals who were submitted to polysomnography and structured interviews. We subdivided our sample into five-year age groups. One-way analysis of variance was used to compare age groups. Pearson product–moment was used to evaluate correlation between age and sleep parameters.
Results: Total sleep time, sleep efficiency, percentage of rapid eye movement (REM) sleep and slow wave sleep showed a significant age-related decrease ($P < 0.05$). WASO (night-time spent awake after sleep onset), arousal index, sleep latency, REM sleep latency, and the percentage of stages 1 and 2 showed a significant increase ($P < 0.05$). Furthermore, apnea–hypopnea index increased and oxygen saturation decreased with age. The reduction in the percentage of REM sleep significantly correlated with age in women, whereas the reduction in the percentage of slow wave sleep correlated with age in men. The periodic limb movement (PLM) index increased with age in men and women.
Conclusions: Sleep structure and duration underwent significant alterations throughout the aging process in the general population. There was an important correlation between age, sleep respiratory parameters and PLM index. In addition, men and women showed similar trends but with different effect sizes.

1. Introduction

The understanding of sleep alterations related to aging is important to interpret clinical sleep conditions as normal or pathological. As aging is not a uniform process among individuals and populations, age-related changes in sleep patterns may differ according to the population studied. Epidemiological studies suggest that many sleep alterations typical in elderly people are related to comorbidities present in this age group [1,2]. Some age-related alterations in polysomnographic parameters have been consistently shown, including reductions in total sleep time, sleep efficiency and slow wave sleep, and an increase in WASO (night-time spent awake after sleep onset) [3–8]. Other parameters, such as sleep latency, rapid eye movement (REM) sleep, and stages 1 and 2, showed less consistent correlations [9–11]. Possible reasons for these results are related to methodological limitations, including small samples and confounding factors, such as diseases, substance use, and sleep disturbances. Ohayon et al. performed a large meta-analysis studying sleep structure across the lifespan; even among studies included in this meta-analysis, there were limitations that included small samples and selection biases [3]. To our knowledge, there is a dearth of studies in large adult samples of all ages that are representative of the general population. For this reason, we proposed a study to evaluate the sleep structure in adults (20–80 years) in a representative sample of São Paulo, the largest city in Brazil. Similarly to previous studies we gathered stratified and combined data for each gender in order to highlight gender-specific effects of aging on sleep structure [3].

* Corresponding author. Address: R. Manuel de Paiva 313, São Paulo 04106-020, Brazil. Tel./fax: +55 11 55739238.
E-mail address: walterasmoraes@gmail.com (W. Moraes).

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2. Methods

The present study is part of EPISONO (São Paulo Epidemiologic Study) whose methodology has already been published [12]. Sao Paulo is the largest city in Brazil with 11,253,503 inhabitants [13]. The DATAFOLHA Poll Institute selected a representative sample from all areas of the city that included both genders and all ethnicities [12]. Households were selected if they were permanently occupied private homes. The selection process was random and dwellers of each house were selected by means of random tables. Pregnant and lactating women, individuals with mental and physical disturbances that limit independence and night workers were not included in this sample; further details about sampling procedures are provided in the methodology paper [12]. In all, 165 volunteers were substituted by individuals who matched the same sampling criteria. A total of 1101 questionnaires were delivered at home, and 1042 individuals underwent polysomnography (PSG). Details about inclusion and exclusion criteria and home questionnaires have been described by Santos-Silva et al. regarding the methodology of EPISONO [12]. The protocol was approved by the Ethics Committee of Universidade Federal de São Paulo (CEP 0593/06) and registered at ClinicalTrials.gov (NCT00596713).

2.1. Polysomnography

At the sleep laboratory, the habitual bedtime was observed. A complete full-night PSG was performed using an EMBLA® digital system (EMBLA S7000, Embla Systems Inc., Broomfield, CO, USA) in a sleep laboratory. The following physiological parameters were monitored: four-channel electroencephalography (EEG) (C3–A2, C4–A1, O1–A2 and O2–A1), two-channel electro-oculography (EOG), four-channel surface electromyography (EMG) (submentonian and anterior tibialis), one-channel electrocardiography, an airflow thermistor sensor, a nasal cannula, thoracic and abdominal piezoelectric straps to assess respiratory movements, a snore sensor, a body-position sensor and an oximeter. All recordings were digitally stored, and sleep staging was performed according to standardized criteria [14]. Arousals, respiratory events and limb movements were visually scored according to the American Academy of Sleep Medicine Manual [14]. PSG sleep staging and event scoring were performed by four skilled technicians.

2.2. Statistics

Individuals were grouped into five-year age intervals for both genders. Between-group differences in sleep parameters were analyzed by one-way analysis of variance using Statistica 7 software (Stat Soft Inc., Tulsa, OH, USA). Pearson correlations were calculated between sleep parameters and age. Effect sizes were considered small for $\eta^2 \leqslant 0.01$, moderate for $\eta^2 \geqslant 0.06$ and high for $\eta^2 \geqslant 0.14$ [15].

3. Results

The study included 468 men and 574 women. Both genders showed no significant differences in mean ± SD body mass index (men, 26.6 ± 0.25; women, 27.0 ± 0.22) and sleep duration assessed by PSG (men, 5.7 ± 0.06 h; women, 5.7 ± 0.05 h). As expected, the average age of women was older than that of men (men, 40.7 ± 0.66 years [range, 20–79]; women, 43.7 ± 0.60 [range, 20–80]; $P < 0.05$, *t*-test).

In the general population (men and women), a large effect size was observed for the age-related increase in the arousal index and WASO although increase in arousal index was mainly due to respiratory arousals (Figs 1 and 2, Table 1). Non-respiratory arousal index was different among age groups but showed no clear tendency to increase after the fifth decade (Table 1). A small effect size was observed for the increase in sleep latency, REM sleep latency and percentage of stages 1 and 2 (Table 1). Age-related reduction in total sleep time, sleep efficiency and slow wave sleep duration had a moderate effect size (Fig. 3, Table 1). A small effect size was observed for the reduction in the duration of stage 2, duration of REM sleep, percentage of REM sleep, and percentage of slow-wave sleep (Table 1). There was no significant difference between genders in the following sleep parameters: total sleep time, sleep latency, REM latency, sleep efficiency, periodic limb movement (PLM) index, stages 1, 2, slow wave sleep and REM sleep percentage and time (*t*-test). Sleep stages, WASO and sleep latency results are summarized in Fig. 4.

With respect to respiratory sleep parameters, there was a significant age-related increase in apnea–hypopnea index (AHI) (large effect size, Table 2). There was also an age-related increase in B90, desaturation time, and desaturation index (moderate effect size,

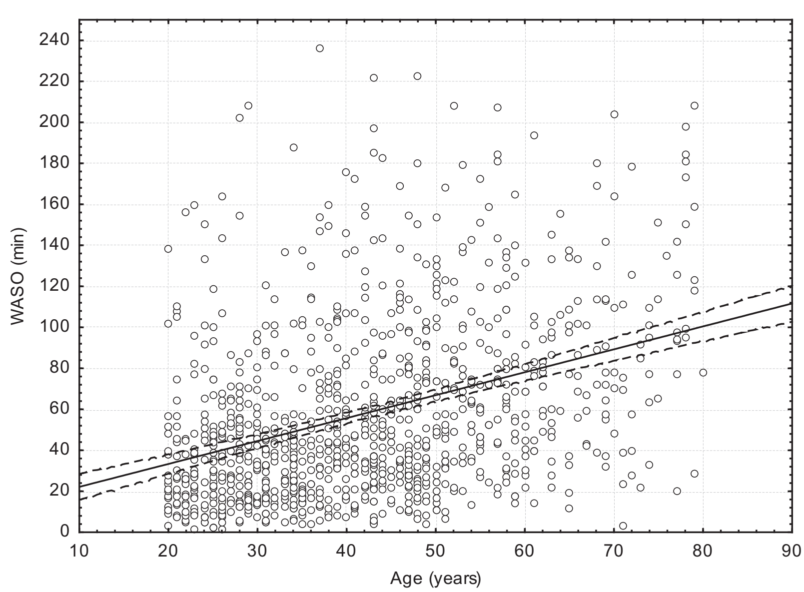

Fig. 1. Correlation between WASO (night-time spent awake after sleep onset) and age.

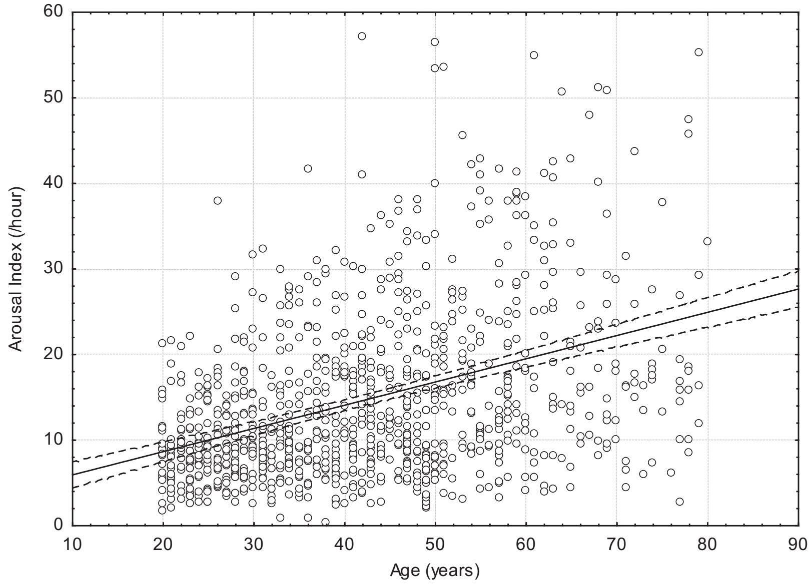

Fig. 2. Correlation between arousal index and age.

Table 2). There was a decrease with age in basal oxygen saturation (basal SaO_2), average oxygen saturation (average SaO_2), and minimum oxygen saturation (minimum SaO_2) (large effect size, Table 2). The PLM index increased with age (moderate effect size, Table 2). Men and women of all age groups showed significant differences in the following sleep respiratory parameters: apnea–hypopnea index (men, 2.0 ± 2.3; women, 0.5 ± 0.8), basal SaO_2 (men, 96.5 ± 1.0; women, 97.4 ± 0.8), average SaO_2 (men, 95.9 ± 1.0; women, 96.9 ± 0.9), minimum SaO_2 (men, 93.1 ± 2.1; women, 93.1 ± 3.2) (t-test, $P < 0.001$).

Men showed an age-related increase in the arousal index and WASO (large effect size, Table 3). There was also an increase, with age, in sleep latency and percentage of stages 1 and 2 (small effect size, Table 3). There was an age-related reduction in sleep efficiency with a high effect size (Table 3). A moderate effect size was observed for the reduction in total sleep time and slow wave sleep (duration and percentage) (Table 3).

For respiratory parameters, men showed a significant age-related increase in AHI, B90 and desaturation index (large effect size, Table 4). Desaturation time also significantly increased (moderate effect size, Table 4). There was an age-related decrease in basal SaO_2, average SaO_2, and minimum SaO_2 (large effect size, Table 4). In addition, the PLM index increased with age (large effect size, Table 4).

An age-related increase in arousal index (large effect size, Table 5) and WASO (moderate effect size, Table 5) was observed in women. There was a reduction in total sleep time, sleep efficiency, duration of stage 2, and duration of REM sleep with a moderate effect size (Table 5). A small effect size was observed for the reduction in the duration of slow wave sleep (Table 5).

Women also showed a significant age-related increase in AHI and desaturation index (large effect size, Table 6). There was also an increase in B90 and desaturation time (moderate effect size, Table 6). There was an age-related decrease in basal SaO_2, average SaO_2, and minimum SaO_2 (large effect size, Table 4). The PLM index increased with age (moderate effect size, Table 6).

The following sleep parameters correlated positively with age in both genders: sleep latency, REM sleep latency, WASO, arousal index, and percentage of stages 1 and 2 (Table 7). The following variables correlated inversely with aging: total sleep time, sleep efficiency, duration of stage 2, percentage of slow wave sleep, duration of slow wave sleep, percentage of REM sleep and duration of REM sleep (Table 7).

In men, sleep latency, WASO arousal index, and percentage of stages 1 and 2 correlated positively with age (Table 7), whereas total sleep time, sleep efficiency, duration of REM sleep, duration of slow wave sleep and percentage of slow wave sleep were inversely associated with age (Table 7).

In women, sleep latency, WASO, the arousal index, and stage 1 time and percentage correlated positively with age (Table 7). The following parameters correlated inversely with age in women: total sleep time, sleep efficiency, duration of stage 2, duration of slow wave sleep, duration of REM sleep and percentage of REM sleep (Table 7).

For both genders, as well as for each separately, the AHI, time spent with oxygen saturation below 90% (B90), desaturation time, and desaturation index correlated positively with age (Table 7). Basal SaO_2, average SaO_2, and minimum SaO_2 were inversely correlated with age (Table 7), while the index of periodic limb movement was correlated positively with age (Table 7).

4. Discussion

To our knowledge, the present study is the first to describe differences in sleep structure among age groups in a large sample that is representative of the general adult population of a large city. Furthermore, we included respiratory sleep disturbances in our model. In this respect, our study may help to clarify contradictory results from previous studies [3,9–11].

The most important previous study was a meta-analysis that included 65 studies [3]. Among other limitations, many studies included in this meta-analysis did not include middle-aged individuals and did not include carefully screened subjects sleeping at habitual sleep hours [3]. Another difficulty inherent to this meta-analysis was that it included only peer-reviewed articles that may be biased towards significant findings [3]. In this respect, our study can add to these previous results.

Most of our results were similar to what was described in this large review [3]. In our study, a moderate effect size was observed for the decrease in total sleep time and sleep efficiency (Fig. 3, Table 1), which confirms the results of previous studies. A large

Table 1
Sleep structure and age.

Sleep structure	Age (years)												P (one-way ANOVA)	Effect size[a]
	20–24 (n = 106)	25–29 (n = 130)	30–34 (n = 129)	35–39 (n = 119)	40–44 (n = 128)	45–49 (n = 126)	50–54 (n = 87)	55–59 (n = 79)	60–64 (n = 48)	65–69 (n = 40)	70–74 (n = 26)	75–80 (n = 24)		
TST	376.3 ± 75.4	367.9 ± 78.4	364.0 ± 71.0	333.4 ± 82.9	338.0 ± 78.1	338.2 ± 74.9	316.9 ± 69.3	325.9 ± 70.9	329.1 ± 51.2	314.5 ± 80.5	292.0 ± 78.0	291.0 ± 66.0	<0.01	0.08
Eff	87.9 ± 9.5	86.1 ± 11.8	86.8 ± 8.6	81.6 ± 15.5	82.5 ± 12.2	81.3 ± 12.5	78.1 ± 13.0	77.7 ± 11.8	79.0 ± 9.6	74.9 ± 14.5	72.8 ± 17.3	65.4 ± 13.0	<0.01	0.13
Lat	13.8 ± 17.5	15.0 ± 20.1	14.5 ± 16.8	19.6 ± 32.7	13.4 ± 13.9	17.4 ± 21.0	17.8 ± 18.7	17.3 ± 18.3	17.3 ± 15.0	20.5 ± 28.7	28.7 ± 41.1	34.6 ± 45.9	0.01	0.03
REMlat	106.4 ± 50.9	97.5 ± 45.5	95.6 ± 44.3	89.8 ± 37.9	97.0 ± 47.5	102.5 ± 57.0	106.1 ± 58.6	109.8 ± 64.2	109.8 ± 65.4	95.0 ± 52.0	129.1 ± 83.1	120.9 ± 3.0	0.01	0.02
WASO	38.9 ± 35.5	44.4 ± 40.5	41.0 ± 30.2	55.0 ± 47.1	58.1 ± 45.8	61.0 ± 45.3	72.3 ± 47.7	78.1 ± 44.9	72.1 ± 37.4	84.1 ± 40.4	81.1 ± 49.2	121.6 ± 49.6	<0.01	0.14
AI	8.8 ± 4.6	10.4 ± 5.8	11.4 ± 6.7	12.5 ± 7.8	15.3 ± 10.6	16.3 ± 13.3	19.6 ± 15.3	19.0 ± 11.1	22.3 ± 14.6	20.9 ± 12.4	17.5 ± 8.8	21.8 ± 13.7	<0.01	0.14
RAI	1.9 ± 2.3	2.4 ± 3.9	3.3 ± 5.1	4.1 ± 5.3	5.9 ± 10.0	7.3 ± 11.3	9.0 ± 11.7	8.6 ± 9.4	13.9 ± 13.6	10.3 ± 9.9	9.6 ± 8.7	13.3 ± 15.2	<0.01	0.13
NRAI	7.1 ± 3.4	7.9 ± 3.8	8.2 ± 4.1	8.5 ± 5.1	9.4 ± 6.4	9.1 ± 5.3	10.7 ± 7.4	10.4 ± 6.3	8.9 ± 5.4	10.8 ± 8.3	8.1 ± 4.7	8.5 ± 5.2	<0.01	0.04
S1d	13.6 ± 9.6	14.3 ± 10.0	14.5 ± 8.8	12.7 ± 8.2	14.9 ± 10.7	16.0 ± 10.3	16.2 ± 13.0	17.3 ± 13.2	15.9 ± 9.4	13.7 ± 5.3	13.3 ± 6.6	18.2 ± 10.1	0.05	0.02
S2d	204.4 ± 52.1	197.4 ± 49.1	197.0 ± 54.6	177.7 ± 53.7	184.7 ± 49.7	181.9 ± 48.4	172.6 ± 47.3	185.4 ± 51.2	184.0 ± 38.5	178.4 ± 56.1	165.7 ± 61.0	169.9 ± 58.4	<0.01	0.04
SWSd	87.4 ± 26.5	83.7 ± 25.3	77.5 ± 25.9	75.4 ± 26.3	69.9 ± 28.9	70.7 ± 30.0	70.2 ± 25.2	63.4 ± 31.9	69.3 ± 26.5	67.2 ± 37.3	63.3 ± 27.0	53.6 ± 33.2	<0.01	0.07
REMd	70.9 ± 30.5	72.6 ± 33.5	75.0 ± 27.6	67.6 ± 28.6	68.5 ± 30.7	69.5 ± 32.3	57.8 ± 26.2	59.9 ± 29.9	60.0 ± 22.2	55.1 ± 22.9	49.6 ± 26.8	49.3 ± 20.6	<0.01	0.05
S1%	3.8 ± 2.9	4.3 ± 4.2	4.1 ± 2.8	4.3 ± 4.1	4.5 ± 3.0	4.8 ± 3.1	5.2 ± 4.0	5.4 ± 4.0	4.9 ± 2.9	4.9 ± 3.3	4.8 ± 2.2	6.4 ± 3.3	<0.01	0.02
S2%	54.2 ± 7.7	53.6 ± 8.5	53.8 ± 8.0	53.0 ± 8.2	55.0 ± 9.3	54.1 ± 9.6	54.5 ± 9.3	57.1 ± 11.6	55.9 ± 8.9	56.7 ± 11.2	55.4 ± 12.4	58.2 ± 13.1	<0.01	0.02
SWS%	23.6 ± 6.7	23.2 ± 6.7	21.8 ± 7.6	23.2 ± 7.7	20.9 ± 7.9	21.3 ± 8.7	22.5 ± 7.8	19.7 ± 9.6	21.1 ± 7.4	21.3 ± 10.2	23.3 ± 11.7	18.3 ± 10.4	<0.01	0.03
REM%	18.4 ± 6.0	19.0 ± 6.9	20.3 ± 5.5	19.5 ± 6.5	19.6 ± 6.4	19.7 ± 6.8	17.8 ± 6.7	17.8 ± 7.2	18.1 ± 5.7	17.0 ± 5.8	16.5 ± 7.1	17.0 ± 6.3	<0.01	0.03

ANOVA, analysis of variance; TST, total sleep time; Eff, sleep efficiency; Lat, sleep latency; REMlat, REM sleep latency (min); WASO, wake after sleep onset; AI, arousal index; RAI, respiratory arousal index; NRAI, non-respiratory arousal index; S1d, stage 1 duration (min); S2d, stage 2 duration (min); SWSd slow wave sleep duration (min); REMd, REM sleep duration; S1%, stage 1 percentage; S2%, stage 2 percentage; SWS%, slow wave sleep percentage; REM%, REM sleep percentage.

Values are mean ± SD.

[a] η^2.

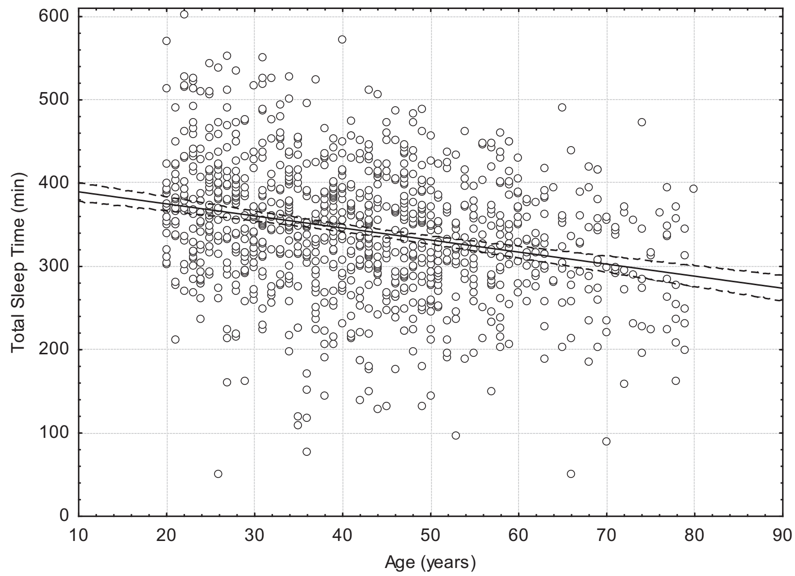

Fig. 3. Correlation between total sleep time and age.

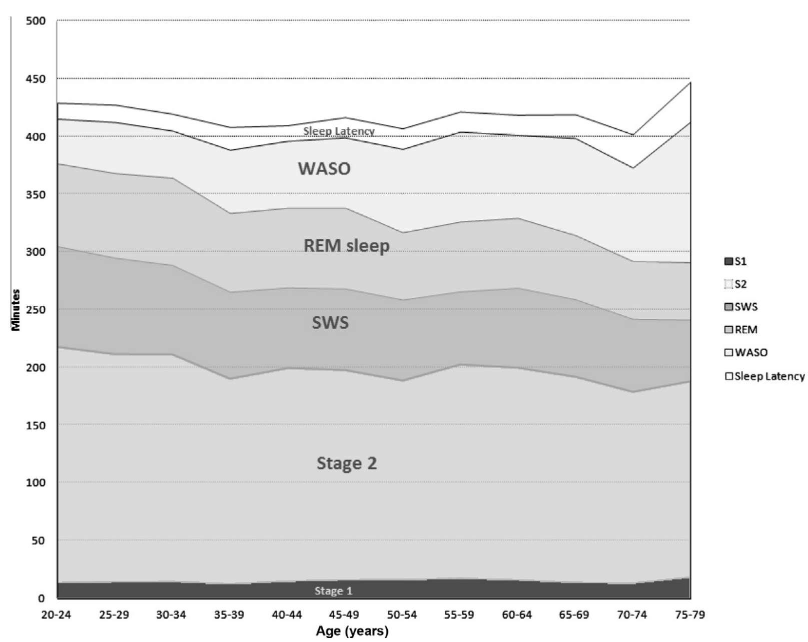

Fig. 4. Relationship between sleep structure and age. WASO, night-time spent awake after sleep onset; REM, rapid eye movement; SWS, slow wave sleep.

effect size was observed for the increase in WASO with age, similar to the findings from Ohayon's meta-analysis (Fig. 1, Table 1). Similarly, sleep latency also tended to increase with age (small effect size). In contrast with this previous review, we observed a high effect size for the increase in the arousal index with age (Fig. 2, Table 1). A few previous studies, with different methodologies and small samples, showed a similar evolution of the arousal index [16,17]. There was a tendency for the percentage of stages 1 and 2 to increase with age in both of the mentioned studies, although the effect sizes and correlations were small. The percentages of slow wave sleep and REM sleep tended to decrease with age in both studies, although in our study the effect sizes and correlations were smaller. Furthermore, the percentage of slow wave sleep showed a significant decrease for men but not for women, whereas the contrary occurred in the percentage of REM (Table 7). Decrease in duration of REM and slow wave sleep was significant for both genders. In our study, there was a small tendency for REM sleep latency to increase after the age of 70 years, whereas in the meta-analysis it tended to decrease [3].

The associations between sleep variables and aging for both genders in our study were similar to the findings of the previous meta-analysis. However, in our study, larger effect sizes were observed in women for total sleep time and arousal index and in men for sleep efficiency, WASO and percentage of slow wave sleep. Small effect sizes were observed for the associations between percentages of stage 1, stage 2 and REM sleep, and between sleep latency and REM latency. In our study, sleep latency did not show a clear tendency toward an increase in duration for men or women when the genders were considered separately. By contrast with our results, larger effect sizes were observed for the associations between all sleep parameters and age in women in the previous meta-analysis. Another difference was that in our study, the reduction in the percentage of REM sleep significantly correlated with age in women (but not men), whereas the reduction in percentage

Table 2
Respiratory sleep parameters, periodic limb movement and age.

Parameters	Age (years)												P (one-way ANOVA)	Effect size[a]
	20–24 (n = 106)	25–29 (n = 130)	30–34 (n = 129)	35–39 (n = 119)	40–44 (n = 128)	45–49 (n = 126)	50–54 (n = 87)	55–59 (n = 79)	60–64 (n = 48)	65–69 (n = 40)	70–74 (n = 26)	75–80 (n = 24)		
AHI	1.4 ± 2.0	2.6 ± 4.8	4.6 ± 8.7	5.7 ± 7.8	7.2 ± 13.1	10.0 ± 13.9	11.1 ± 14.2	11.8 ± 14.1	19.5 ± 21.2	17.2 ± 18.2	15.8 ± 11.8	21.9 ± 20.5	<0.01	0.17
B90	0.5 ± 3.9	0.3 ± 1.3	1.1 ± 4.3	2.0 ± 4.9	4.7 ± 23.5	6.8 ± 24.7	5.8 ± 13.9	17.5 ± 48.6	16.1 ± 32.7	16.1 ± 28.8	38.4 ± 71.8	21.1 ± 36.6	<0.01	0.10
Dest	0.1 ± 1.0	0.1 ± 0.4	0.3 ± 1.2	0.6 ± 1.5	1.5 ± 8.2	1.8 ± 6.2	1.7 ± 3.9	5.0 ± 13.2	4.9 ± 10.4	7.1 ± 16.8	11.9 ± 20.9	6.5 ± 11.1	<0.01	0.10
Desi	1.6 ± 4.3	2.7 ± 4.0	4.1 ± 7.6	5.0 ± 6.9	7.0 ± 11.5	7.0 ± 10.3	8.2 ± 11.0	9.4 ± 12.1	15.5 ± 19.9	12.9 ± 13.7	11.3 ± 10.0	16.6 ± 17.7	<0.01	0.12
BasalS	96.9 ± 1.0	96.7 ± 1.2	96.6 ± 1.1	96.2 ± 1.3	96.0 ± 1.5	95.8 ± 1.6	95.5 ± 1.2	94.8 ± 1.9	94.8 ± 1.5	94.6 ± 1.4	94.2 ± 1.8	94.0 ± 1.5	<0.01	0.26
AvS	96.3 ± 1.1	96.2 ± 1.3	96.0 ± 1.3	95.4 ± 1.4	95.3 ± 2.3	95.0 ± 1.7	94.6 ± 1.6	93.9 ± 2.1	93.9 ± 1.7	93.6 ± 1.9	92.9 ± 2.2	93.0 ± 1.7	<0.01	0.25
MinS	92.0 ± 2.8	91.6 ± 2.8	90.2 ± 4.4	89.1 ± 4.8	88.8 ± 6.4	87.5 ± 5.4	86.6 ± 5.3	84.8 ± 6.5	84.3 ± 5.6	83.6 ± 6.8	82.8 ± 5.5	84.0 ± 6.7	<0.01	0.22
PLMi	0.7 ± 2.8	0.7 ± 2.3	1.4 ± 5.0	3.2 ± 9.9	3.1 ± 10.0	4.3 ± 10.6	3.7 ± 9.3	9.1 ± 16.3	8.0 ± 13.0	10.6 ± 22.4	10.5 ± 19.2	10.0 ± 17.3	<0.01	0.08

ANOVA, analysis of variance; AHI, apnea hypopnea index; B90, time spent with oxygen saturation below 90%; Dest, desaturation time; Desi, desaturation index; BasalS, basal oxygen saturation; AvS, average oxygen saturation; MinS, minimum oxygen saturation; PLMi, periodic limb movement index.
Values are mean ± SD.
[a] η^2.

Table 3
Sleep structure and age (men).

Sleep structure	Age (years)												P (one-way ANOVA)	Effect size[a]
	20–24 (n = 60)	25–29 (n = 60)	30–34 (n = 65)	35–39 (n = 59)	40–44 (n = 56)	45–49 (n = 48)	50–54 (n = 38)	55–59 (n = 30)	60–64 (n = 20)	65–69 (n = 14)	70–74 (n = 10)	75–80 (n = 8)		
TST	377.0 ± 83.3	367.6 ± 88.0	359.7 ± 66.7	341.3 ± 74.6	337.7 ± 69.6	330.0 ± 73.6	323.1 ± 64.9	314.2 ± 69.6	331.6 ± 54.6	330.9 ± 64.9	308.1 ± 101.0	289.6 ± 71.7	<0.01	0.08
Eff	87.5 ± 9.3	85.4 ± 13.3	86.6 ± 9.0	83.2 ± 12.7	81.6 ± 11.4	79.9 ± 12.9	79.6 ± 10.4	75.8 ± 13.7	78.5 ± 9.7	74.6 ± 11.6	72.9 ± 20.1	60.6 ± 13.5	<0.01	0.15
Lat	15.4 ± 20.0	16.5 ± 25.9	14.8 ± 16.9	16.3 ± 21.2	13.9 ± 16.2	17.5 ± 20.8	16.8 ± 15.0	14.6 ± 15.5	14.8 ± 14.1	21.5 ± 17.0	34.5 ± 56.5	49.0 ± 71.1	0.01	0.05
REMlat	107.5 ± 54.6	95.1 ± 42.9	90.2 ± 36.2	84.1 ± 38.4	92.5 ± 46.0	101.3 ± 54.6	103.8 ± 48.6	96.1 ± 69.6	102.8 ± 66.4	92.8 ± 66.2	104.1 ± 79.6	114.4 ± 79.6	0.47	0.02
WASO	39.0 ± 33.8	46.0 ± 41.2	41.1 ± 30.6	51.5 ± 41.8	62.1 ± 41.9	67.3 ± 49.7	66.0 ± 35.2	85.8 ± 47.6	77.6 ± 38.6	92.3 ± 40.8	76.0 ± 30.2	138.7 ± 38.4	<0.01	0.18
AI	9.3 ± 5.1	12.1 ± 6.8	13.6 ± 8.0	13.7 ± 8.6	19.6 ± 13.4	21.3 ± 17.3	21.6 ± 16.8	23.7 ± 10.3	23.2 ± 17.6	26.5 ± 13.1	19.3 ± 10.2	25.9 ± 15.5	<0.01	0.17
S1d	14.7 ± 10.8	15.1 ± 9.1	15.6 ± 9.7	13.3 ± 8.3	16.5 ± 12.3	18.1 ± 11.5	19.4 ± 15.8	16.9 ± 8.4	15.4 ± 9.8	16.3 ± 5.3	11.9 ± 6.3	23.4 ± 10.9	0.12	0.04
S2d	203.6 ± 56.8	195.2 ± 55.1	192.7 ± 52.4	176.7 ± 48.3	186.6 ± 50.5	180.9 ± 44.4	177.9 ± 50.6	181.9 ± 48.0	188.8 ± 37.2	192.4 ± 42.1	182.3 ± 87.2	164.2 ± 50.7	0.20	0.03
SWSd	88.3 ± 26.6	82.6 ± 28.7	77.4 ± 26.0	78.9 ± 25.0	65.1 ± 31.2	62.7 ± 28.5	63.9 ± 23.6	59.0 ± 33.0	66.4 ± 29.2	58.6 ± 31.1	58.8 ± 27.4	47.3 ± 30.3	<0.01	0.13
REMd	70.4 ± 29.4	74.7 ± 33.0	74.0 ± 24.9	72.5 ± 28.2	69.5 ± 30.4	68.3 ± 30.2	61.9 ± 22.4	56.5 ± 30.6	61.0 ± 22.3	63.7 ± 23.1	55.1 ± 28.3	54.7 ± 25.9	0.05	0.04
S1%	4.1 ± 3.1	4.8 ± 5.2	4.5 ± 3.2	4.1 ± 2.7	5.0 ± 3.7	5.7 ± 3.6	6.1 ± 4.8	5.9 ± 4.0	4.6 ± 2.8	5.2 ± 2.3	4.2 ± 2.2	8.1 ± 3.3	0.03	0.05
S2%	53.8 ± 7.5	52.7 ± 9.5	53.3 ± 8.1	51.6 ± 7.7	55.7 ± 11.1	55.4 ± 9.7	54.6 ± 9.1	58.3 ± 11.7	57.0 ± 7.4	58.5 ± 8.9	55.3 ± 17.7	57.7 ± 13.9	0.05	0.04
SWS%	23.9 ± 6.3	22.9 ± 6.7	21.8 ± 7.2	23.8 ± 7.8	19.4 ± 8.9	19.1 ± 7.5	20.1 ± 7.6	18.6 ± 9.4	19.9 ± 7.5	17.3 ± 7.8	23.1 ± 16.0	16.1 ± 8.7	<0.01	0.07
REM%	18.3 ± 5.4	19.6 ± 6.5	20.3 ± 5.3	20.6 ± 5.9	19.9 ± 6.8	19.8 ± 6.5	19.1 ± 5.9	17.2 ± 8.0	18.4 ± 5.9	19.0 ± 4.9	17.5 ± 6.9	18.1 ± 6.3	0.36	0.03

ANOVA, analysis of variance; TST, total sleep time; Eff, sleep efficiency; Lat, sleep latency; REMlat, REM sleep latency (min); WASO, wake after sleep onset; AI, arousal index; S1d, stage 1 duration (min); S2d, stage 2 duration (min); SWSd, slow wave sleep duration (min); REMd, REM sleep duration; S1%, stage 1 percentage; S2%, stage 2 percentage; SWS%, slow wave sleep percentage; REM%, REM sleep percentage.
Values are mean ± SD.
[a] η^2.

Table 4
Respiratory sleep parameters: periodic limb movement and age (men).

Parameters	Age (years)												P (one-way ANOVA)	Effect size[a]
	20–24 (n = 60)	25–29 (n = 60)	30–34 (n = 65)	35–39 (n = 59)	40–44 (n = 56)	45–49 (n = 48)	50–54 (n = 38)	55–59 (n = 30)	60–64 (n = 20)	65–69 (n = 14)	70–74 (n = 10)	75–80 (n = 8)		
AHI	2.1 ± 2.3	4.4 ± 6.2	7.8 ± 11.2	7.9 ± 8.8	13.3 ± 17.6	16.0 ± 17.5	12.1 ± 14.3	15.2 ± 13.1	20.9 ± 21.5	19.1 ± 17.3	16.9 ± 14.5	31.3 ± 23.5	<0.01	0.18
B90	0.2 ± 0.9	0.3 ± 1.6	2.2 ± 5.9	3.0 ± 6.1	10.3 ± 35.3	11.3 ± 33.7	5.3 ± 11.3	15.4 ± 31.4	13.4 ± 20.9	14.8 ± 33.8	54.1 ± 86.2	11.0 ± 12.6	<0.01	0.12
Dest	0.1 ± 0.3	0.1 ± 0.4	0.6 ± 1.7	0.9 ± 1.8	3.3 ± 12.4	2.9 ± 8.0	1.7 ± 3.4	4.6 ± 8.7	3.8 ± 5.8	4.4 ± 9.8	16.3 ± 25.4	3.5 ± 3.8	<0.01	0.13
Desi	1.5 ± 2.0	3.2 ± 4.1	5.9 ± 9.6	6.6 ± 8.0	10.6 ± 14.5	10.2 ± 13.0	8.5 ± 12.0	10.5 ± 10.3	16.5 ± 17.3	13.0 ± 14.3	11.1 ± 13.4	21.5 ± 21.8	<0.01	0.14
BasalS	96.5 ± 1.0	96.3 ± 1.1	96.1 ± 1.2	95.6 ± 1.1	95.2 ± 1.6	95.2 ± 1.7	95.7 ± 1.2	94.3 ± 1.6	94.7 ± 1.4	94.8 ± 1.3	93.7 ± 2.2	93.7 ± 1.1	<0.01	0.24
AvS	95.9 ± 1.0	95.7 ± 1.1	95.4 ± 1.4	94.8 ± 1.1	94.3 ± 2.8	94.5 ± 1.8	95.0 ± 1.5	93.5 ± 1.7	93.9 ± 1.4	94.0 ± 1.9	92.8 ± 2.6	92.8 ± 1.4	<0.01	0.20
MinS	91.2 ± 2.2	90.5 ± 2.3	88.6 ± 5.3	87.5 ± 5.4	86.3 ± 7.4	86.5 ± 5.3	87.1 ± 5.4	83.6 ± 6.8	84.5 ± 6.0	83.9 ± 8.9	83.9 ± 4.6	84.1 ± 2.5	<0.01	0.17
PLMi	0.9 ± 3.6	0.4 ± 1.6	1.3 ± 4.7	1.6 ± 4.3	1.8 ± 6.0	5.7 ± 12.6	5.7 ± 12.8	13.2 ± 20.9	9.2 ± 12.4	13.2 ± 29.4	20.8 ± 27.5	21.7 ± 24.5	<0.01	0.18

ANOVA, analysis of variance; AHI, apnea hypopnea index; B90, time spent with oxygen saturation below 90%; Dest, desaturation time; Desi, desaturation index; BasalS, basal oxygen saturation; AvS, average oxygen saturation; MinS, minimum oxygen saturation; PLMi, periodic limb movement index.
Values are mean ± SD.
[a] η^2.

Table 5
Sleep structure and age (women).

Sleep structure	Age (years)												P (one-way ANOVA)	Effect size[a]
	20–24 (n = 46)	25–29 (n = 70)	30–34 (n = 64)	35–39 (n = 60)	40–44 (n = 72)	45–49 (n = 78)	50–54 (n = 49)	55–59 (n = 49)	60–64 (n = 28)	65–69 (n = 26)	70–74 (n = 16)	75–80 (n = 16)		
TST	375.5 ± 64.5	368.2 ± 69.9	368.5 ± 75.4	325.7 ± 90.3	338.2 ± 84.6	343.2 ± 75.8	312.1 ± 72.9	333.1 ± 71.5	327.4 ± 49.7	305.6 ± 87.6	281.9 ± 61.2	291.7 ± 65.5	<0.01	0.10
Eff	88.5 ± 9.9	86.6 ± 10.4	87.0 ± 8.3	80.1 ± 17.8	83.3 ± 12.8	82.2 ± 12.3	76.9 ± 14.6	78.8 ± 10.4	79.3 ± 9.6	75.0 ± 16.1	72.7 ± 16.0	67.8 ± 12.4	<0.01	0.13
Lat	11.6 ± 13.4	13.6 ± 13.4	14.2 ± 16.7	22.8 ± 41.0	13.1 ± 11.9	17.3 ± 21.3	18.6 ± 21.3	19.0 ± 19.8	19.1 ± 15.6	20.0 ± 33.6	25.0 ± 29.3	27.5 ± 26.6	0.07	0.03
REMlat	104.9 ± 46.3	99.5 ± 47.7	101.0 ± 50.9	95.7 ± 36.7	100.6 ± 48.6	103.3 ± 58.8	107.9 ± 66.1	118.0 ± 60.0	114.9 ± 65.5	96.3 ± 43.6	144.8 ± 83.9	124.2 ± 80.9	0.08	0.03
WASO	38.8 ± 37.8	43.1 ± 40.2	40.9 ± 30.0	58.4 ± 51.9	55.0 ± 48.7	57.1 ± 42.2	77.1 ± 55.3	73.3 ± 43.0	68.2 ± 36.7	79.7 ± 40.3	84.4 ± 58.8	113.1 ± 53.4	<0.01	0.13
AI	8.2 ± 3.9	8.9 ± 4.2	9.2 ± 1.4.0	11.2 ± 6.8	11.9 ± 6.0	13.2 ± 8.8	18.1 ± 14.0	16.1 ± 10.7	21.6 ± 12.3	17.9 ± 11.2	16.4 ± 8.0	19.7 ± 12.8	<0.01	0.18
S1d	12.2 ± 7.6	13.6 ± 10.7	13.3 ± 7.8	12.2 ± 8.1	13.7 ± 9.3	14.7 ± 9.4	13.8 ± 9.7	17.6 ± 15.5	16.3 ± 9.2	12.3 ± 4.8	14.2 ± 6.8	15.6 ± 8.9	0.22	0.02
S2d	205.4 ± 46.0	199.2 ± 43.6	201.4 ± 56.8	178.7 ± 58.9	183.2 ± 49.3	182.5 ± 50.9	168.5 ± 44.6	187.5 ± 53.5	180.5 ± 39.8	170.9 ± 61.9	155.4 ± 36.6	172.7 ± 63.2	<0.01	0.06
SWSd	86.4 ± 26.7	84.5 ± 22.2	77.6 ± 25.9	72.1 ± 27.3	73.6 ± 26.5	75.7 ± 30.0	75.1 ± 25.5	66.2 ± 31.2	71.3 ± 24.7	71.9 ± 40.0	66.1 ± 27.2	56.7 ± 35.0	<0.01	0.05
REMd	71.6 ± 32.3	70.8 ± 34.1	76.1 ± 30.2	62.8 ± 28.4	67.7 ± 31.1	70.2 ± 33.7	54.6 ± 28.7	61.9 ± 29.5	59.2 ± 22.5	50.5 ± 21.9	46.2 ± 26.2	46.6 ± 17.8	<0.01	0.07
S1%	3.4 ± 2.5	3.9 ± 3.1	3.7 ± 2.4	4.5 ± 5.1	4.1 ± 2.3	4.3 ± 2.7	4.6 ± 3.2	5.1 ± 4.0	5.1 ± 3.0	4.8 ± 3.8	5.1 ± 2.1	5.6 ± 3.1	0.13	0.02
S2%	54.7 ± 8.1	54.3 ± 7.6	54.3 ± 8.1	54.5 ± 8.5	54.4 ± 7.7	53.3 ± 9.5	54.5 ± 9.5	56.4 ± 11.7	55.1 ± 9.8	55.8 ± 12.3	55.5 ± 8.2	58.5 ± 13.1	0.77	0.01
SWS%	23.3 ± 7.3	23.4 ± 6.8	21.7 ± 7.9	22.7 ± 7.6	22.1 ± 6.8	22.7 ± 9.2	24.3 ± 7.6	20.3 ± 9.8	22.0 ± 7.4	23.5 ± 10.7	23.4 ± 8.8	19.4 ± 11.3	0.45	0.02
REM%	18.6 ± 6.7	18.5 ± 7.3	20.3 ± 5.7	18.4 ± 6.9	19.3 ± 6.2	19.7 ± 7.0	16.7 ± 7.1	18.2 ± 6.8	17.9 ± 5.6	15.9 ± 6.0	16.0 ± 7.4	16.5 ± 6.4	0.05	0.03

ANOVA, analysis of variance; TST, total sleep time; Eff, sleep efficiency; Lat, sleep latency; REMlat, REM sleep latency (min); WASO, wake after sleep onset; AI, arousal index; S1d, stage 1 duration (min); S2d, stage 2 duration (min); SWSd, slow wave sleep duration (min); REMd, REM sleep duration; S1%, stage 1 percentage; S2%, stage 2 percentage; SWS%, slow wave sleep percentage; REM%, REM sleep percentage.
Values are mean ± SD.
[a] η^2.

Table 6
Respiratory sleep parameters, periodic limb movements and age (women).

Parameters	Age (years)												P (one-way ANOVA)	Effect size[a]
	20–24 (n = 46)	25–29 (n = 70)	30–34 (n = 64)	35–39 (n = 60)	40–44 (n = 72)	45–49 (n = 78)	50–54 (n = 49)	55–59 (n = 49)	60–64 (n = 28)	65–69 (n = 26)	70–74 (n = 16)	75–80 (n = 16)		
AHI	0.5 ± 0.8	1.0 ± 2.0	1.3 ± 2.0	3.5 ± 6.1	2.4 ± 4.1	6.3 ± 9.4	10.4 ± 14.2	9.7 ± 14.4	18.5 ± 21.2	16.2 ± 18.9	15.0 ± 10.1	17.1 ± 17.7	<0.01	0.23
B90	0.9 ± 5.7	0.2 ± 1.1	0.0 ± 0.1	1.0 ± 3.1	0.5 ± 1.4	4.0 ± 16.5	6.3 ± 15.8	18.7 ± 56.7	18.1 ± 39.8	16.7 ± 26.7	27.9 ± 61.3	26.2 ± 43.6	<0.01	0.10
Dest	0.2 ± 1.4	0.1 ± 0.4	0.0 ± 0.0	0.3 ± 0.9	0.2 ± 0.5	1.2 ± 4.7	1.8 ± 4.3	5.2 ± 15.4	5.8 ± 12.9	8.4 ± 19.4	9.0 ± 17.7	8.0 ± 13.3	<0.01	0.11
Desi	2.1 ± 7.6	2.0 ± 3.8	1.8 ± 2.8	3.0 ± 4.7	3.0 ± 3.8	5.0 ± 7.7	7.9 ± 10.3	8.8 ± 13.1	14.8 ± 21.8	12.9 ± 13.6	11.4 ± 7.5	13.2 ± 14.3	<0.01	0.16
BasalS	97.4 ± 0.8	97.1 ± 1.1	97.2 ± 0.7	96.7 ± 1.3	96.7 ± 1.0	96.2 ± 1.4	95.3 ± 1.3	95.2 ± 1.9	94.9 ± 1.6	94.4 ± 1.4	94.5 ± 1.4	94.1 ± 1.6	<0.01	0.38
AvS	96.9 ± 0.9	96.6 ± 1.3	96.6 ± 0.9	96.0 ± 1.4	96.0 ± 1.2	95.4 ± 1.6	94.3 ± 1.6	94.2 ± 2.3	94.0 ± 1.9	93.3 ± 2.0	93.0 ± 1.9	93.1 ± 1.9	<0.01	0.39
MinS	93.1 ± 3.2	92.5 ± 2.7	91.8 ± 2.4	90.6 ± 3.6	90.7 ± 4.7	88.1 ± 5.4	86.3 ± 5.2	85.5 ± 6.3	84.1 ± 5.3	83.4 ± 5.5	82.1 ± 6.0	83.9 ± 8.1	<0.01	0.38
PLMi	0.3 ± 1.2	0.9 ± 2.7	1.5 ± 5.4	4.8 ± 13.1	4.0 ± 12.2	3.4 ± 9.2	2.1 ± 4.8	6.7 ± 12.3	7.1 ± 13.6	9.3 ± 18.1	4.0 ± 6.6	4.1 ± 8.0	<0.01	0.06

ANOVA, analysis of variance; AHI, apnea hypopnea index; B90, time spent with oxygen saturation below 90%; Dest, desaturation time; Desi, desaturation index; BasalS, basal oxygen saturation; AvS, average oxygen saturation; MinS, minimum oxygen saturation; PLMi, periodic limb movement index.
Values are mean ± SD.
[a] η^2.

Table 7
Correlations between sleep parameters and age.

Parameters	Both genders		Men		Women	
	R	P	R	P	R	P
TST	−0.27	<0.01	−0.26	<0.01	−0.27	<0.01
Lat	0.12	<0.01	0.11	<0.01	0.12	<0.01
REMLat	0.08	<0.01	0.02	0.58	0.11	<0.01
Eff	−0.34	<0.01	−0.36	<0.01	−0.33	<0.01
WASO	0.35	<0.01	0.39	<0.01	0.33	<0.01
AI	0.36	<0.01	0.38	<0.01	0.39	<0.01
RAI	0.35	<0.01	0.37	<0.01	0.41	<0.01
NRAI	0.13	<0.01	0.11	<0.05	0.16	<0.01
S1d	0.07	0.01	0.09	0.04	0.08	0.04
S2d	−0.16	<0.01	−0.11	0.01	−0.19	<0.01
SWSd	−0.25	<0.01	−0.33	<0.01	−0.25	<0.01
REMd	−0.20	<0.01	−0.17	<0.01	−0.22	<0.01
S1%	0.13	<0.01	0.14	<0.01	0.15	<0.01
S2%	0.11	<0.01	0.16	<0.01	0.06	0.12
SWS%	−0.10	<0.01	−0.21	<0.01	−0.04	0.36
REM%	−0.09	<0.01	−0.05	0.26	−0.11	<0.01
AHI	0.39	<0.01	0.39	<0.01	0.46	<0.01
B90	0.28	<0.01	0.28	<0.01	0.27	<0.01
Dest	0.28	<0.01	0.28	<0.01	0.29	<0.01
BasalS	−0.50	<0.01	−0.46	<0.01	−0.60	<0.01
AvS	−0.49	<0.01	−0.41	<0.01	−0.61	<0.01
MinS	−0.48	<0.01	−0.39	<0.01	−0.57	<0.01
MinS	−0.48	<0.01	−0.39	<0.01	−0.57	<0.01
Desi	0.38	<0.01	0.34	<0.01	0.38	<0.01
PLMi	0.27	<0.01	0.39	<0.01	0.17	<0.01

TST = total sleep time, WASO = wake after sleep onset, S1% = stage 1 percentage, S1d = stage 1 duration (minutes), 1 S2% = stage 2 percentage, S2d = stage 2 duration (minutes), SWS% = slow wave sleep percentage, SWSd = slow wave sleep duration (minutes), REM% = REM sleep percentage, REMd = REM sleep duration (minutes), Lat = sleep latency, RAI = repiratory arousal index, NRAI = nonrespiratory arousal index, AI = arousal index, Eff = sleep efficiency, AHI = apnea hypopnea index, BasalS = basal oxygen saturation, AvS = average oxygen saturation, Dest = desaturation time, B90 = time spent with oxygen saturation below 90% MinS minimum oxygen saturation, Desi = desaturation index, PLMi = periodic limb movement index.

of slow wave sleep correlated with age in men (but not women) (Table 7).

The evolution of the different sleep stages, WASO and sleep latency throughout adulthood is shown in Fig. 4, which clearly shows a tendency toward a reduction in sleep duration and an increase in WASO. The increase in WASO was more evident in the last decade included in this study. Fig. 4 is very similar to Fig. 2 presented in the meta-analysis described above [3].

We also assessed sleep respiratory parameters and confirmed previous findings that aging is related to increased AHI [18–20]. We found a substantial reduction of oxygen saturation during sleep in older individuals, a result that differed from a previous study, which found a decrease in mean SaO_2 during wakefulness but not during sleep [18]. In our study, these effects were important both in men and women. Similarly to previous studies, we found a strong correlation between increased PLM index and age [21,22]. There was a moderate to large effect of age for the PLM index for both men and women.

The main limitations of the present study are that it is a cross-sectional study and consequently does not show the evolution of the same individuals with aging, but rather, different individuals in different age groups. Another limitation is that a single PSG night was evaluated, allowing some influence of first night effect.

The results of this epidemiological study describe the association between age and PSG sleep parameters in a large and multiracial city. The understanding of the evolution of sleep structure throughout adulthood is important to provide a better interpretation of PSG data in future research and clinical practice. More studies are necessary to understand the physiological mechanisms involved in this process.

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Conflict of interest

The ICMJE Uniform Disclosure Form for Potential Conflicts of Interest associated with this article can be viewed by clicking on the following link: http://dx.doi.org/10.1016/j.sleep.2013.11.791.

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